

What is claimed is:

1. A bandgap reference generator comprising:
a current mirror circuit having two current paths, a first current path passing through a first MOS transistor and a first bipolar junction transistor; a second current path passing through a second MOS transistor, a resistor, and a second bipolar junction transistor, wherein a current through said resistor is indicative of a difference in voltages across the first and second bipolar junction transistors; and
a high impedance control circuit coupled between a drain and gate of said second MOS transistor.
2. The bandgap of claim 1 wherein the resistor is trimmable.
3. A bandgap reference generator comprising:
a current mirror circuit having two current paths, a first current path passing through a first MOS transistor and a first bipolar junction transistor; a second current path passing through a second MOS transistor, a resistor, and a second bipolar junction transistor, wherein a current through said resistor is indicative of a difference in voltages across the first and second bipolar junction transistors; and
a high impedance voltage shifter coupled between a drain and gate of said second MOS transistor.
4. The bandgap of claim 3 wherein the resistor is trimmable.
5. A bandgap reference generator comprising:
a first circuit including a first MOS transistor of a first type, a first MOS transistor of a second type, and a first bipolar junction transistor;
a second circuit comprising a second MOS transistor of the first type, a second MOS transistor of the second type, a resistor, and a second bipolar junction transistor, the first and

second circuits being arranged to provide a current through the resistor indicative of a difference in voltages across the first and second bipolar junction transistors, the MOS transistors of the first type being arranged as a mirror; and

a high impedance control circuit coupled between a drain and gate of said second MOS transistor of the first type.

6. A bandgap reference generator comprising:

a first circuit including a first MOS transistor of a first type, a first MOS transistor of a second type, and a first bipolar junction transistor;

a second circuit comprising a second MOS transistor of a first type, a second MOS transistor of the second type, a resistor, and a second bipolar junction transistor, the first and second circuits being arranged to provide a current through the resistor indicative of a difference in voltages across the first and second bipolar junction transistors, the MOS transistors of the first type being arranged as a mirror;

a high impedance control circuit coupled between a drain and gate of said second MOS transistor of the first type; and

a sampling switch to periodically sample positive temperature and negative temperature coefficient currents in said second circuit.

7. The bandgap of claim 6 wherein the current is trimmable through the resistor.

8. A bandgap reference generator comprising:

a first circuit including a first MOS transistor of a first type, a first MOS transistor of a second type, and a first bipolar junction transistor;

a second circuit comprising a second MOS transistor of a first type, a second MOS transistor of the second type, a resistor, and a second bipolar junction transistor, the first and second circuits being arranged to provide a current through the resistor indicative of the difference in voltages across the first and second bipolar junction transistors, the MOS transistors of the first type being arranged as a mirror; and

a high impedance voltage shifter coupled between a drain and gate of said second MOS transistor of the first type.

9. The bandgap of claim 8 wherein the voltage shifting is trimmable.

10. A bandgap reference generator comprising:

a first circuit including a first MOS transistor of a first type, a first MOS transistor of a second type, and a first bipolar junction transistor;

a second circuit comprising a second MOS transistor of a first type, a second MOS transistor of the second type, a resistor, and a second bipolar junction transistor, the first and second circuits being arranged to provide a current through the resistor indicative of the difference in voltages across the first and second bipolar junction transistors, the MOS transistors of the first type being arranged as a mirror; and

a high impedance voltage shifter coupled between a drain and gate of said first MOS transistor of the second type.

11. A bandgap reference generator comprising:

a first MOS transistor of a first type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to a voltage node;

a first MOS transistor of a second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the second terminal of the first MOS transistor of the first type and to said gate;

a first bipolar junction transistor including an emitter coupled to the second terminal of the first MOS transistor of the second type, including a collector coupled to a ground node, and including a base coupled to said collector;

a second MOS transistor of the first type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel,

said first terminal being coupled to said voltage node, said gate being coupled to the gate of the first MOS transistor of the first type;

a second MOS transistor of the second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the second terminal of the second MOS transistor of the first type, said gate being coupled to the gate of the first MOS transistor of the second type;

a first resistor including first and second terminals, said first terminal being coupled to the second terminal of the second MOS transistor of the second type;

a second bipolar junction transistor including an emitter coupled to the second terminal of the first resistor, including a collector coupled to said ground node, and including a base coupled to said collector; and

a control circuit including an input coupled to the second terminal of the second MOS transistor of the first type and an output coupled to the gate of the second MOS transistor of the first type.

12. The bandgap reference generator of claim 11 wherein the control circuit biases said first and second transistors of the first type.

13. The bandgap reference generator of claim 11 wherein the control circuit comprises a voltage level shifter.

14. The bandgap reference generator of claim 13 wherein the control circuit comprises a buffer coupled to the input of the control circuit and said voltage level shifter is coupled to the output of the control circuit.

15. The bandgap reference generator of claim 11 further comprising a switch coupled between the emitter and the collector of the second bipolar junction transistor to selective short said emitter to said collector.

16. The bandgap reference generator of claim 11 wherein the control circuit comprises a buffer having an input coupled to the input of the control circuit and having an output, comprises a second resistor including a first terminal coupled to the output of the buffer and including a second terminal coupled to the output of the control circuit, and comprises a third resistor including a first terminal coupled to the second terminal of the second resistor and including a second terminal coupled to a ground node.

17. The bandgap reference generator of claim 11 wherein the control circuit comprises a third transistor of the second type including first and second terminals spaced apart with a channel therebetween and a gate for controlling current in said channel, said first terminal is coupled to another voltage node and said gate is coupled to the input of the control circuit, the control circuit further comprises a second resistor including a first terminal coupled to the second terminal of the third transistor of the second type and including a second terminal coupled to the output of the control circuit, and comprises a third resistor including a first terminal coupled to the second terminal of the second resistor and including a second terminal coupled to a ground node.

18. A bandgap reference generator comprising:

a first MOS transistor of a first type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to a voltage node;

a first MOS transistor of a second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the second terminal of the first MOS transistor of the first type;

a first bipolar junction transistor including an emitter coupled to the second terminal of the first MOS transistor of the second type, including a collector coupled to a ground node, and including a base coupled to said collector;

a second MOS transistor of the first type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel,

said first terminal being coupled to said voltage node, said gate being coupled to the gate of the first MOS transistor of the first type;

a second MOS transistor of the second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the second terminal of the second MOS transistor of the first type and to the gate of the first MOS transistor of the second type;

a first resistor including first and second terminals, said first terminal being coupled to the second terminal of the second MOS transistor of the second type;

a second bipolar junction transistor including an emitter coupled to the second terminal of the first resistor, including a collector coupled to said ground node, and including a base coupled to said collector;

a first control circuit including an input coupled to the first terminal of the first MOS transistor of the second type and an output coupled to the gate of the first MOS transistor of the second type; and

a second control circuit including an input coupled to the second terminal of the second MOS transistor of the first type and an output coupled to the gate of the second MOS transistor of the first type.

19. The bandgap reference generator of claim 18 wherein the first and second control circuits each comprise a voltage level shifter.

20. The bandgap reference generator of claim 19 wherein the first and second control circuits each comprise a buffer.

21. The bandgap reference generator of claim 18 further comprising a switch coupled between an emitter and collector of the second bipolar junction transistor to selectively short said emitter to said collector.

22. The bandgap reference generator of claim 18,

wherein the first control circuit comprises a first buffer having an input coupled to the input of the first control circuit and having an output, comprises a second resistor including a first terminal coupled to the output of the first buffer and including a second terminal coupled to the output of the first control circuit, and comprises a third resistor including a first terminal coupled to the second terminal of the second resistor and including a second terminal coupled to another voltage node,

wherein the second control circuit comprises a second buffer having an input coupled to the input of the second control circuit and having an output, comprises a fourth resistor including a first terminal coupled to the output of the second buffer and including a second terminal coupled to the output of the second control circuit, and comprises a fifth resistor including a first terminal coupled to the second terminal of the fourth resistor and including a second terminal coupled to a ground node.

23. The bandgap reference generator of claim 18,

wherein the first control circuit comprises a third transistor of the first type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said second terminal is coupled to a ground node and said gate is coupled to the input of the first control circuit, comprises a second resistor including a first terminal coupled to the first terminal of the third transistor of the first type and including a second terminal coupled to the output of the first control circuit, and comprises a third resistor including a first terminal coupled to the second terminal of the second resistor and including a second terminal coupled to another voltage node,

the second control circuit comprises a third transistor of the second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal is coupled to another voltage node and said gate is coupled to the input of the second control circuit, comprises a fourth resistor including a first terminal coupled to the second terminal of the third transistor of the second type and including a second terminal coupled to the output of the second control circuit, and comprises a

fifth resistor including a first terminal coupled to the second terminal of the fourth resistor and including a second terminal coupled to a ground node.

24. The bandgap reference generator of claim 18, wherein the first control circuit comprises a third transistor of the second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to another voltage node and said gate is coupled to the input of the first control circuit, comprises a second resistor including a first terminal coupled to the second terminal of the third transistor of the second type and including a second terminal coupled to the output of the first control circuit, and comprises a third resistor including a first terminal coupled to the second terminal of the second resistor and including a second terminal coupled to the ground node,

the second control circuit comprises a fourth transistor of the second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal is coupled to said another voltage node and said gate is coupled to the input of the second control circuit, comprises a fourth resistor including a first terminal coupled to the second terminal of the fourth transistor of the second type and including a second terminal coupled to the output of the second control circuit and comprises a fifth resistor including a first terminal coupled to the second terminal of the fourth resistor and including a second terminal coupled to said ground node.

25. A bandgap reference generator comprising:

a first transistor of a first type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to a voltage node;

a second transistor of the first type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the second terminal of the first transistor of the first type;

a first transistor of a second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the second terminal of the second transistor of the first type;

a second transistor of the second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the second terminal of the first transistor of the second type;

a first bipolar junction transistor including an emitter coupled to the second terminal of the second transistor of the second type, including a collector coupled to a ground node, and including a base coupled to said collector;

a third transistor of the first type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling a gate in said channel, said first terminal being coupled to said voltage node, said gate being coupled to the gate of the first transistor of the first type;

a fourth transistor of the first type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the second terminal of the third transistor of the first type, said gate being coupled to the gate of the second transistor of the first type;

a third transistor of the second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the second terminal of the fourth transistor of the first type, said gate being coupled to the gate of the first transistor of the second type;

a fourth transistor of the second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the second terminal of the third transistor of the second type, said gate being coupled to the gate of the second transistor of the second type;

a first resistor including first and second terminals, said first terminal being coupled to the second terminal of the fourth transistor of the second type;

a second bipolar junction transistor including an emitter coupled to the second terminal of the first resistor, including a collector coupled to the ground node, and including a base coupled to said collector;

a first control circuit including a first input coupled to the first terminal of the first transistor of the second type, including a first output coupled to the gate of the first transistor of the second type, and including a second output coupled to the gate of the second transistor of the second type; and

a second control circuit including a first input coupled to the second terminal of the fourth transistor of the first type, including a first output coupled to the gate of the third transistor of the first type, including a second output coupled to the gate of the fourth transistor of the first type.

26. The bandgap reference generator of claim 25 wherein the first control circuit comprises a fifth transistor of the second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the voltage node, said gate being coupled to the first input of the first control circuit, comprises a second resistor including a first terminal coupled to the second terminal of the fifth transistor of the second type and including a second terminal coupled to the first output of the first control circuit, comprises a third resistor including a first terminal coupled to the second terminal of the second resistor and including a second terminal coupled to the second output of the first control circuit, and comprises a fourth resistor including a first terminal coupled to the second terminal of the third resistor and including a second terminal coupled to the ground node,

wherein the second control circuit comprises a sixth transistor of the second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the voltage node, said gate being coupled to the first input of the second control circuit, comprises a fifth resistor including a first terminal coupled to the second terminal of the sixth transistor of the second type and including a second terminal coupled to the first output of the second control circuit,

comprises a sixth resistor including a first terminal coupled to the second terminal of the second fifth and including a second terminal coupled to the second output of the second control circuit, and comprises a seventh resistor including a first terminal coupled to the second terminal of the sixth resistor and including a second terminal coupled to the ground node.

27. The bandgap reference generator of claim 25 further comprising a switch coupled between the emitter and the collector of the second bipolar junction transistor to selectively short said emitter to said collector.

28. The bandgap reference generator of claim 25 wherein the first control circuit comprises a fifth transistor of the second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the voltage node, said gate being coupled to the first input of the first control circuit, comprises a second resistor including a first terminal coupled to the second terminal of the fifth transistor of the second type and including a second terminal coupled to the first output of the first control circuit, comprises a third resistor including a first terminal coupled to the second terminal of the second resistor and including a second terminal coupled to the second output of the first control circuit, comprises a fourth resistor including a first terminal coupled to the second terminal of the third resistor and including a second terminal, and comprises a sixth transistor of the second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said second terminal being coupled to the ground node, said first terminal being coupled to the second terminal of the fourth resistor, and said gate being coupled to an enable signal node,

wherein the second control circuit comprises a seventh transistor of the second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the voltage node, said gate being coupled to the first input of the second control circuit, comprises a fifth resistor including a first terminal coupled to the second terminal of the sixth transistor of the second type and including a second terminal coupled to the first output of the second control circuit,

comprises a sixth resistor including a first terminal coupled to the second terminal of the second fifth and including a second terminal coupled to the second output of the second control circuit, comprises a seventh resistor including a first terminal coupled to the second terminal of the sixth resistor and including a second terminal, comprises an eighth transistor of the second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said second terminal being coupled to the ground node, said first terminal being coupled to the second terminal of the seventh resistor, and said gate being coupled to the enable signal node.

29. The bandgap reference generator of claim 28 wherein the second control circuit further comprises a fifth transistor of the second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the voltage node, said second terminal being coupled to the first output of the second control circuit, and said gate being coupled to said enable signal node.

30. The bandgap reference generator of claim 28 wherein the enable signal node is a power down signal node.

31. The bandgap reference generator of claim 28 wherein the first and second control circuits include a power down circuit.

32. The bandgap reference generator of claim 31 further comprising a biasing circuit for biasing the first and second control circuits.

33. The bandgap reference generator of claim 28 wherein the first control circuit comprises a ninth transistor of the second type including the first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the first terminal of the sixth transistor of the second type, said second terminal being coupled to the second terminal of the sixth transistor of the second type, the

second control circuit further comprises a tenth transistor of the second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the first terminal of the eighth transistor of the second type, said second terminal being coupled to the second terminal of said eighth transistor of the second type,

the bandgap reference generator further comprising a biasing circuit for biasing the ninth and tenth transistors of the second type.

34. The bandgap reference generator of claim 33 wherein the biasing circuit comprises a fifth transistor of the first type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the voltage node, said gate being coupled to the gate of the first transistor of the first type, comprising a sixth transistor of the first type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the second terminal of the fifth transistor of the first type, said gate being coupled to the gate of the second transistor of the first type, and comprises an eleventh transistor of the second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to said gate and to said second terminal of the sixth transistor of the first type, said second terminal being coupled to the ground node, said gate being coupled to the gates of the ninth and tenth transistors of the second type.

35. The bandgap reference generator of claim 32 further comprising a startup circuit to provide a startup current.

36. The bandgap reference generator of claim 35 wherein the startup circuit comprises a seventh transistor of the first type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the voltage node, said gate being coupled to the ground node,

comprising an eighth transistor of the first type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the second terminal of the seventh transistor of the first type, said gate being coupled to the ground node, comprising an eleventh transistor of the second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said second terminal being coupled to the ground node, said first terminal being coupled to the second terminal of the eighth transistor of the first type, said gate being coupled to said first terminal, comprising a thirteenth transistor of the second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the first terminal of the eleventh transistor of the second type, said second terminal being coupled to the second terminal of the eleventh transistor of the second type, said gate being coupled to the first terminal of the eleventh transistor of the second type, and comprises a fourteenth transistor of the second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the gate of the first transistor of the first type, said second terminal being coupled to said ground node, said gate being coupled to the first terminal of the eleventh transistor of the second type.

37. The bandgap reference generator of claim 28 further comprising a switch coupled between the emitter and the collector of the second bipolar junction transistor to selectively short said emitter to said collector.

38. The bandgap reference generator of claim 37 wherein the switch is dynamically opened and closed to sample currents in the fourth MOS transistor of the second type.

39. The bandgap reference generator of claim 28 wherein the first control circuit comprises a fifth transistor of the second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the voltage node, said gate being coupled to the first input of the first

control circuit, comprises a second resistor including a first terminal coupled to the second terminal of the fifth transistor of the second type and including a second terminal coupled to the first output of the first control circuit, comprises a third resistor including a first terminal coupled to the second terminal of the second resistor and including a second terminal coupled to the second output of the first control circuit, comprises a fourth resistor including a first terminal coupled to the second terminal of the third resistor and including a second terminal, and comprises a first current source including a first terminal coupled to the second terminal of the fourth resistor and including a second terminal coupled to the ground node,

wherein the second control circuit comprises a sixth transistor of the second type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the voltage node, said gate being coupled to the first input of the second control circuit, comprises a fifth resistor including a first terminal coupled to the second terminal of the sixth transistor of the second type and including a second terminal coupled to the first output of the second control circuit, comprises a sixth resistor including a first terminal coupled to the second terminal of the second fifth and including a second terminal coupled to the second output of the second control circuit, comprises a seventh resistor including a first terminal coupled to the second terminal of the sixth resistor and including a second terminal, and comprises a second current source including a first terminal coupled to the second terminal of the seventh resistor and including a second terminal coupled to the ground node.

40. The bandgap reference generator of claim 39 further comprising an eighth resistor including a first terminal coupled to the emitter of the second bipolar junction transistor and including a second terminal coupled to the collector of the second bipolar junction transistor.

41. The bandgap reference generator of claim 40 further comprising an output circuit.

42. The bandgap reference generator of claim 41 wherein the output circuit comprises a fifth transistor of the first type including first and second terminals spaced apart with a channel

therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the voltage node, said gate being coupled to the gate of the first transistor of the first type, comprises a sixth transistor of the first type including first and second terminals spaced apart with a channel therebetween and including a gate for controlling current in said channel, said first terminal being coupled to the second terminal of the fifth transistor of the first type, said gate being coupled to the gate of the second transistor of the first type, and comprises a ninth resistor including a first terminal coupled to the second terminal of the sixth transistor of the first type to form an output node and including a second terminal coupled to the ground node.

43. A system comprising:
 - a memory array;
 - a fuse circuit; and
 - a bandgap reference generator of claim 11.
44. A system comprising:
 - a memory array;
 - a fuse circuit; and
 - a bandgap reference generator of claim 5.
45. A system comprising:
 - a memory array;
 - a fuse circuit; and
 - a bandgap reference generator of claim 6.
46. A system comprising:
 - a memory array;
 - a fuse circuit; and
 - a bandgap reference generator of claim 8.

47. A system comprising:
- a memory array;
 - a fuse circuit; and
 - a bandgap reference generator of claim 10.